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METHOD FOR RECEIVING SPECTRUM SPREADING SIGNALS WITH FREQUENCY SHIFT CORRECTION

Technical field

The object of the present invention is a method for receiving spectrum spreading signals with frequency shift correction. It finds an application in digital
5   transmissions.

With the invention, effects due to untimely frequency shifts may be corrected, regardless of the origin of these shifts. Most often, this will be a Doppler effect related to the moving speed of the
10   receiver. But this might also be effects due to a frequency shift of the local oscillators. In the description which follows, it will be assumed that the effect to be corrected is a Doppler effect, without however limiting the scope of the invention to this
15   case.

Prior state of the art

A great number of publications have been made on the correction of the Doppler effect. For example,
20   patent US-A-5 007 068 may be mentioned as well as the corresponding article of M. K. SIMON and D. DIVSALAR entitled "Doppler-Corrected Differential Detection of MPSK", published in the journal, "IEEE Transactions on Communications", Vol. 37, No. 2, February 1989, pages
25   99-109. These documents describe a technique wherein the Doppler shift is determined on one half of the symbol period. For this purpose, the receiver uses two circuits each with a half period delay, and a Doppler effect estimation circuit connected between the two
30   delay circuits. The correction is then performed on the

usual demodulated signal.

This technique may also be used for modulations of the multiple differential phase modulation type (abbreviated as MDPSK for "M-ary Differential Phase Shift Keying"), but it is not applicable to spectrum spreading transmissions where each symbol is multiplied by a pseudo-random sequence.

The article of F. D. NATALI, entitled "AFC Tracking Algorithms", published in the journal, "IEEE Translations on Communications, vol. COM-32, No. 8, August 1984, pages 935-947, describes a technique in which preambles made up of known symbols are formed before transmitting the useful information. The working frequency is automatically controlled ("Automatic Frequency Control" or AFC) by a loop structure.

This technique is not adapted to the case when information data blocks separated by blanks are transmitted.

The following correction techniques may further be mentioned:

- the use of double detection, which gets rid of the Doppler effect by suitable encoding (US-A-4 481 640);

- the use of the frequency mixing principle in the radio portion of the receivers (US-A-4 706 286);

- the use of a phase locked loop (PLL) in the radio portion (US-A-4 841 544);

- the use of a dual mode with increased throughput (US-A-5 623 485).

These techniques are generally expensive and complex and do not make the most out of the advantages of spectrum spreading, nor of the digital processing of the signals. The object of the present invention is

precisely to overcome these drawbacks by providing a method which processes the signals in the base band (and not the signals in the radio portion) and which is well adapted to digital processing.

5   Document EP-A-0 822 668 describes a receiver for spectrum spreading signals wherein the Doppler effect correction is performed on the base band signal.

Description of the invention

10   Specifically, the object of the invention is a method for receiving spectrum spreading signals with frequency shift correction, wherein:

- a signal is received comprising a preamble made up from a sequence of known symbols spread in frequency

15 by a pseudo-random sequence, followed by a sequence of information symbols spread in frequency by said pseudo-random sequence,

- a base band signal is formed from the received signal,

20   - a correlation is performed between the base band signal and the pseudo-random sequence at least in the portion of the signal corresponding to the information symbols, in order to obtain a correlation signal,

- a demodulation of the correlation signal is

25 performed in order to obtain a demodulation signal,

- the information symbols are restored,
a method wherein the frequency shift correction comprises the following steps:

a. in a first step, the demodulation signal is

30   processed in the portion corresponding to the preamble, in order to estimate the period of the modulation affecting the signal because of the frequency shift and a correcting signal

with this estimated period is elaborated,

b. in a second step, the signal is corrected
   before or after the correlation in the portion
   corresponding to the information symbols, by
5 means of said correcting signals,

the method being characterized in that:

- the base band signal is divided into two
  components, a first component (I) and a second
  component (Q) in quadrature with the first and
10 a correlation is performed on each of these
  components in order to obtain two correlation
  components CORR (I) and CORR (Q),

- a DOT signal is calculated which is the sum of
  two direct products of successive samples of
15 the correlation components, and a CROSS signal
  is calculated which is the difference between
  two crossed products of successive samples of
  the correlation components,

- in order to estimate the period (T) of the
20 modulation, the ratio between a CROSS signal
  and a DOT signal is calculated at each symbol
  period, the arc is calculated for which the
  tangent is equal to this ratio, the inverse of
  this arc is calculated and multiplied by $\pi N/2$.

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Brief description of the drawings

- Fig. 1 is a reminder of the general structure of
  a spreading spectrum signal receiver;
- Fig. 2 shows a correlation signal corresponding
30 to a signal not affected by the Doppler effect;
- Fig. 3 shows this same signal affected by a
  slight Doppler effect;
- Fig. 4 shows this same signal but with a very

strong Doppler effect;

- Fig. 5 illustrates the sinusoidal modulation affecting a correlation signal because of the Doppler effect and it shows the period T of this

5   modulation;

- Fig. 6 is a block diagram showing the estimation of the Doppler modulation from the DOT and CROSS demodulation signals;

- Fig. 7 illustrates an embodiment of a unit for

10   estimating the modulation period and for forming the correction signal for the Doppler effect;

- Fig. 8 illustrates an embodiment of a correction circuit for the Doppler effect;

- Figs. 9A and 9B show a correlation signal before

15   and after correction for the I channel;

- Figs. 10A and 10B show a correlation signal before and after correction for the Q channel;

- Figs. 11A and 11B show a correlation signal before and after correction on the I channel,

20   with Gaussian noise;

- Figs. 12A and 12B show a correlation signal before and after correction on the Q channel, with Gaussian noise;

- Fig. 13 schematically illustrates the structure

25   of a receiver with parallel suppression of interferences and weighting, with Doppler effect correction according to the invention;

- Fig. 14 shows the variations of the bit error rate versus the signal to noise ratio and

30   enables the performances of a receiver according to the invention to be compared with other receivers of known types.

Description of the particular embodiments

Fig. 1 is a reminder of the general structure of a direct sequence spectrum spreading signal receiver. As an example, it is assumed that the modulation carried out at emission is a phase difference modulation. The receiver comprises means not shown such as an antenna and means for switching to base band, i.e. in order to multiply the received signal by a signal with the frequency of the carrier. The receiver generally includes two parallel channels, marked by indices I and Q, for the processing of a signal in phase with the carrier and a signal in phase quadrature with the latter. The illustrated receiver thus comprises two inputs E(I), E(Q), two analog-digital converters ADC(I), ADC(Q), two circuits F(I), F(Q) delivering two CORR(I) and CORR(Q) signals, a differential demodulation (DD) circuit delivering two signals, conventionally marked as "DOT" and "CROSS" (which are sums or differences of sample products at the correlation output), a circuit Inf/H restoring an information signal Sinf and a clock signal SH, and finally a decision circuit D, the output of which restores data d.

Circuits F(I), F(Q) perform a correlation operation between the received signal and the pseudo-random sequence used at emission. This operation consists in storing a certain number of successive samples and in performing a weighted sum with the help of coefficients which are the coefficients for direct sequence spectrum spreading. These coefficients are equal to +1 and to -1, according to the sign of the chips forming the pseudo-random sequence.

The analog-digital converters ADC(I) and ADC(Q)

operate at frequency $n_e F_c$ where F_c is the frequency of the chip ($F_c = 1/T_c$), and n_e is the number of samples taken in a chip period (T_c). To simplify the discussion, it will be assumed that one sample is taken

5 per chip. The correlation signals CORR(I) and CORR(Q) contain one correlation peak per symbol period.

As for the DOT and CROSS signals delivered by the demodulation circuit DD, as a reminder, they are for the first, the sum $I_k I_{k-1} + Q_k Q_{k-1}$ and for the second, the

10 difference $Q_k I_{k-1} - I_k Q_{k-1}$, where I_k and Q_k designate the correlation samples of rank k for channels I and Q, the rank corresponding to a symbol period (I_k corresponds to CORR (I_k) and Q_k to CORR (Q_k)).

Fig. 2 shows the sequence of the correlation peaks

15 in the ideal case of a preamble made up of binary data each equal to +1, the transmission being not affected by a Doppler effect. Fig. 2 relates both to channel I and channel Q. The time counted in chip periods appears on the abscissa. These peaks are separated from each

20 other by N chips. In the illustrated case, N = 31. All the peaks have the same amplitude, in the ideal case, without any noise.

Fig. 3 illustrates the same case, but with a slight Doppler effect, while Fig. 4 illustrates the

25 case of a strong Doppler effect. The frequency shift due to the Doppler effect is expressed by a phase shift of the processed signal and by a parasitic modulation of the correlation signal.

Fig. 5 resumes this matter in a more accurate way

30 and shows the modulation related to the perturbation with its half-period marked as T, which is the time (counted in the number of chips) separating two successive extrema. The total period of the parasitic

modulation is therefore equal to 2T. The method of the present invention enables this parasitic modulation to be corrected. According to the invention, this is carried out in two steps: first of all, the period T (or its double 2T) is measured, so that a correction signal may be elaborated; then the signals are corrected by said correction signal.

In order to estimate the time T (or 2T), according to the invention, the correlation signals are used as DOT and CROSS signals.

To carry out the correction, either the incident signals or the correlation signals are acted upon. There are therefore several possible alternatives which are illustrated in Figs. 6-8. In these figures, the notations have been slightly changed with respect to those of Fig. 1, in the sense that the signals before their processing bear a "DOP" index, to notify that they are affected by Doppler effect, the signals after processing being cleared of this index.

In Fig. 6, the Doppler effect estimation circuit EST_{dop} processes demodulation signals $DOT_{dop}(I)$ and/or $CROSS_{dop}(Q)$. Correction is carried out either on I_{dop} and Q_{dop}, or on $CORR_{dop}(I)$ and $CORR_{dop}(Q)$, in circuit CC_{dop}.

The properties of the signals to be processed are used for determining the period T illustrated in Fig. 5 (or 2T). Indeed, it may be considered that the correlation signals corresponding to a preamble are made up of the samples of a cosine wave and of a sine wave of a half-period T, sampled every kN chips (cf. Fig. 5). This may therefore be written as:

$$CORR_{dop}(I_k) = P.\cos(\pi kN/2T) \qquad (1)$$

$$CORR_{dop}(Q_k) = P.\sin(\pi kN/2T) \qquad (2)$$

where P is an amplitude.

After differential demodulation, the following DOT and CROSS signals are obtained:

$DOT_{dop}(k) = CORR_{dop}(I_k).CORR_{dop}(I_{k-1}) + CORR_{dop}(Q_k).CORR_{dop}(Q_{k-1})$ (3)

5   $CROSS_{dop}(k) = CORR_{dop}(Q_k).CORR_{dop}(I_{k-1}) - CORR_{dop}(I_k).CORR_{dop}(Q_{k-1})$ (4)

By replacing in (3), (4) the quantities with their values given by (1) and (2) and taking into account the properties of trigonometric functions, it is found

10   that:

$$DOT_{dop}(k) = P^2. \cos(\pi N/2T) \qquad (5)$$

$$CROSS_{dop}(k) = P^2. \sin(\pi N/2T) \qquad (6)$$

15   It is seen that both DOT_{dop} and $CROSS_{dop}$ quantities are independent of the rank k of the preamble symbol.

By taking the ratio of these quantities, the tangent of angle $\pi N/2T$ is formed from which the angle and the value of T may be extracted:

$$T = \frac{\pi.N/2}{\tan^{-1}\left(\dfrac{CROSS_{dop}(k)}{DOT_{dop}(k)}\right)} \qquad (7)$$

where $\tan^{-1}(.)$ means "arc for which the tangent is equal

25   to (.)".

The Doppler effect estimation circuit EST_{dop} of Fig. 6 is therefore simply a circuit comprising a divider for signals A = $CROSS_{dop}$ and B = DOT_{dop}, a circuit for calculating $\tan^{-1}(A/B)$, an inverter and a multiplier

30   by $N\pi/2$. T being known, a correction signal needs to be generated for which one component Cc is a cosine and the other Cs a sine:

$$Cc = \cos(\pi x/2T) \qquad (8)$$

$$Cs = \sin(\pi x/2T) \qquad (9)$$

Such a signal is generated by a generator with two quadrature outputs.

5   This calculation may be changed by taking a sequence of weighted samples and calculating:

$$T = \frac{\pi.N/2}{\tan^{-1}\left[\dfrac{(1-\alpha).\sum\limits_{k=0}^{\infty}\alpha^k CROSS_{dop}(k)}{(1-\alpha).\sum\limits_{k=0}^{\infty}\alpha^k DOT_{dop}(k)}\right]} \qquad (10)$$

Still in a more general way, estimation of T is improved by proceeding with low pass filtering of 15 signals DOT_{dop} and $CROSS_{dop}$, i.e., with $A=f(CROSS_{dop}(k))$ and $B=f(DOT_{dop}(K))$, where f represents the filtering function:

$$T = \frac{\pi.N/2}{\tan^{-1}\left[\dfrac{A}{B}\right]} \qquad (11)$$

A generator receiving T, delivers components Cs and Cs as defined by (8) and (9).

Fig. 7 illustrates a particular embodiment of the 25 estimation circuit. This circuit comprises two amplifiers 10, 11 with gain (1-α), two multipliers 12, 13, the output of which is fed back to a second input as a loop by an amplifier 14, 15 via a delay line 16, 17. The circuit is completed by means for applying the 30 relation (11), i.e., a divider 20, a circuit 22 for calculating the arc tangent, a circuit 24 which calculates the inverse of the arc tangent, and an amplifier 26 with gain $\pi N/2$ which delivers quantity T.

A generator 30 receiving T delivers components Cc and Cs as defined by (8) and (9).

Having described the means for obtaining both components Cc and Cs of the correction signal, a description will now be made on how the received signals are corrected accordingly. This correction processes the signals carrying the transmitted information and no longer the preamble.

Generally, the correlation signals CORR(I) and CORR(Q) of the phase and quadrature channels may be considered as real and imaginary components of a complex signal CORR(I) + jCORR(Q). The Doppler effect changes the phase of this signal (in other words, it rotates the vector which represents it) by a quantity $e^{j(\pi x/2T)}$. The obtained signal is the Doppler effect affected signal. Its components are $CORR_{dop}(I)$ and $CORR_{dop}(Q)$. This may be therefore written as:

$$CORR_{dop}(I) + jCORR_{dop}(Q) = [CORR(I) + jCORR(Q)]e^{j(\pi x/2T)} \qquad (12)$$

Conversely, the components free from the Doppler effect may be expressed with respect to the components impaired by the Doppler effect as:

$$CORR(I) + jCORR(Q) = [CORR_{dop}(I) + jCORR_{dop}(Q)]e^{-j(\pi x/2T)} \qquad (13)$$

By developing the right-hand member of this equation and by identifying the real and imaginary terms, it is found that:

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$$CORR(I) = CORR_{dop}(I).cos(\pi x/2T) + CORR_{dop}(Q).sin(\pi x/2T) \qquad (14)$$

$$CORR(Q) = CORR_{dop}(Q).\cos(\pi x/2T) - CORR_{dop}(I).\sin(\pi x/2T) \quad (15)$$

The same relationships may be established with signals I and Q, i.e.:

$$[I + jQ] = [I_{dop} + jQ_{dop}]e^{-j(\pi x/2T)} \qquad (16)$$

i.e.:

$$I = I_{dop}.\cos(\pi x/2T) + Q_{dop}.\sin(\pi x/2T) \quad (17)$$
$$Q = Q_{dop}.\cos(\pi x/2T) - I_{dop}.\sin(\pi x/2T) \quad (18)$$

The correction circuit must therefore comprise multipliers for multiplying the signals to be corrected by both components of the correction signal, and adders in order to perform the sum of the obtained products. Fig. 8 shows an example of such a circuit. As illustrated, it comprises two multipliers 41 and 42 receiving I_{dop} or $CORR_{dop}(I)$ and $\cos(\pi x/2T)$ for the first and Q_{dop} or $CORR_{dop}(Q)$ and $\sin(\pi x/2T)$ for the second, respectively, and an adder 43 connected to both multipliers in order to deliver the signal from the first channel corrected from the Doppler effect, i.e., I or CORR(I). Similarly, the circuit further comprises two multipliers 51 and 52 receiving Q_{dop} or $CORR_{dop}(Q)$ and $\cos(\pi x/2T)$ for the first and I_{dop} or $CORR_{dop}(I)$ and $\sin(\pi x/2T)$ for the second, respectively, and an adder 53 with an inverting input (in other words a subtractor), the inverting input being connected to multiplier 52 and the other input to multiplier 51. This adder 53 delivers the signal of the second channel

corrected from the Doppler effect, i.e., Q or CORR(Q).

Figs. 9A, 9B and 10A, 10C, on the one hand, as well as 11A, 11B and 12A, 12B, on the other hand, illustrate the correction which has just been
5 described.

In Fig. 9A, first of all, a correlation signal of channel I is seen before correction and affected by a Doppler effect. In Fig. 9B, this effect has been corrected.

10 In Figs. 10A and 10B, the same signals are seen before and after correction, but on channel Q.

Figs. 11A, 11B and 12A, 12B show the same signals but in the presence of noise such that a signal to noise ratio is 5 dB.

15 The invention is not limited to the case when both channel I and channel Q are corrected. One or the other of these channels might as well be corrected. The correction circuit will then implement the portion of the means required for calculating expressions (18)
20 or (19).

The invention, which has just been described, is applied to any type of pseudo-random sequence spectrum spreading signal receiver. In particular it may be applied to so-called Code Division Multiple Access
25 (CDMA) transmissions. In these transmissions, several users share a same channel by means of different pseudo-random sequences. The receiver then comprises as many parallel channels as users. In a particular embodiment, such a CDMA receiver may comprise parallel
30 suppression means for interference between users, with weighting means. Such a receiver is described in a French patent application filed by the present applicant on Marsh 24th 1998, under number 98 03586.

Fig. 13 schematically illustrates such a receiver. As illustrated, it comprises a general input E, receiving a composite signal R(t), K parallel channels V_1, V_2, ..., V_K, where K is the maximum number of users,

5   each channel delivering a signal $R_1(T)$, $R_2(T)$, ..., $R_K(T)$, specific to each user, a weighted interference parallel suppression circuit (SPIP) and K decision circuits D_1, D_2, ..., D_K, delivering data d_1, d_2, ..., d_K, specific to each of the users.

10   Finally Fig. 14 enables the performances of a receiving method according to the invention to be compared with conventional methods. This figure 13 shows the variations of the bit error rate (BER) versus the signal to noise ratio SNR. Fig. 13 makes the

15   assumption of K = 5 users with N = 63. The Doppler effect was simulated by a shift with respect to the carrier of the local oscillator.

Curve 50 refers to a conventional method with one stage, without interference suppression. Curves 51 and

20   52 refer to the same method but with two different Doppler effects, the first with a relative shift of 10^{-6} at 2.45 GHz and the second with a relative shift of 10^{-5}.

Curve 60 refers to an interference parallel

25   suppression method with only one stage for parallel suppression of interferences and curves 61, 62 to the same method but with shifts of 10^{-6} and 10^{-5}.

Curve 70 refers to a method with two stages for parallel suppression of interferences with associated

30   curves 71, 72 for shifts at 10^{-6} and 10^{-5}.

Finally, curve 80 marks the theoretical limit of the phase difference modulation technique (DQPSK).